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Biological Treatment of Toxics in Wastewater
The Problems and Opportunities

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BIOLOGICAL TREATMENT OF TOXICS IN WASTEWATER: THE PROBLEMS AND OPPORTUNITIES

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16. ABSTRACT

EPA research on toxics control in wastewater treatment involves three approaches: (1) specific toxics treatability to determine the respective contribution of the three removal mechanisms in conventional wastewater treatment; (2) toxicity detection and reduction in treatment and pretreatment; and (3) innovative concepts to enhance control of toxics in biological treatment. The goals of the treatability research is to develop predictive procedures to estimate the fate of specific toxics in conventional wastewater treatment. Progress in developing the data on the removal mechanisms of partitioning, volatilization and biodegradation is described. Toxicity reduction evaluation (TRE) studies are being used to isolate and trace the causes of toxicity pass-through in treatment, to identify the specific toxics, and to evaluate treatment and pretreatment approaches to reduce toxicity pass-through. Innovative concepts to enhance toxic control include control of the toxic discharge rates into treatment; use of additives such as clays, binding proteins, carbons, enzymes, etc.; use of anaerobic-aerobic treatment combinations, use of bioengineered organisms, and the use of special reactors and operational approaches at central treatment plants to improve toxics removals.

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BIOLOGICAL TREATMENT OF TOXICS IN WASTEWATER: THE PROBLEMS AND OPPORTUNITIES

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INTRODUCTION

In 1976, with the consent decree on priority pollutants (1), the regulatory emphasis in the Clean Water Act for water pollution control in the United States shifted from regulation based upon conventional pollutants to regulations based upon specific toxics and conventional pollutants. Since that time, the Environmental Protection Agency's (EPA's) regulatory policy for control of toxics in wastewaters has evolved from effluent limitations, guidelines and standards for the primary industrial point sources for selected specific toxics to, in 1985, a National "Policy for the Development of Water Quality-Based Permit Limitations for Toxic Pollutants" (2). The water quality-based permit approach uses sensitive bioassays to indicate toxicity to the ecosystem of wastewater effluents. The approach also employs increasingly sensitive specific chemical monitoring to detect the discharge of specific toxics in wastewaters.

By itself, the water quality-based permit approach, with its broad and evolving detection capabilities, creates a

challenge to the wastewater treatment industry to develop effective and economical techniques to control toxics in wastewaters. Parallel regulatory efforts on toxic and hazardous chemicals under the Toxic Substances Control Act, the Safe Drinking Water Act and the Resources Conservation and Recovery Act further strengthen the need for innovated wastewater treatment technology to manage toxic wastes in wastewaters.

For the Agency's regulatory policies on toxic and hazardous wastes to be effective, the Office of Research and Development must identify or develop practical and cost-effective approaches for control of these wastes. These approaches can be conveniently divided into the following general areas:

- waste reduction through industrial in-plant process modifications, recovery and reuse of toxics,
- biological treatment (aerobic and anaerobic) including advanced bioengineering concepts,
- physical-chemical treatment, and
- waste containment and immobilization.

A brief perspective on these areas as applied to toxics in wastewater is appropriate. The use of industrial in-plant process modification and toxics recovery and reuse is a desirable approach for minimizing toxic problems in wastewaters. Recovery and reuse will occur when the recovery cost is less than the costs of the treatment alternatives. Indeed, in the future with the increasing detection sensitivity for toxics and toxicity and improved risk assessment definition, the water quality-based permit approach can only encourage waste reduction efforts through in-plant recovery and reuse. For some wastes, recovery and reuse may be the only effective mechanism for environmental control.

Control of toxics through improved treatment, however, will remain an important tool for pragmatic management of toxics in wastewaters. As a treatment generality, EPA's experience has revealed that biological treatment usually is technically more effective and less costly than physical-chemical treatment for control of organic pollutants in wastewaters, especially those waters with complex mixtures of wastes. In some cases, a combination of biological and physical-chemical treatment may be the optimum treatment combination. Additionally, waste containment and immobilization

techniques, such as landfills and other storage systems, offer at best solutions for only certain specialized toxics or hazardous wastes and do not provide satisfactory control for the bulk of the toxic and hazardous wastes in wastewaters. Thus, the regulatory challenge of consistently effective and economical treatment of toxics and hazardous wastes in wastewater hinges strongly on innovative biological treatment.

This Conference, thus, directly responds to the Agency's broad regulatory challenge. The individual papers that will be given here describe the direction and progress of research on the use of innovative biological treatment for control of toxics in wastewaters. In this address, we will describe the approach and scope of the Office of Research and Development's program for improving toxics control in wastewater treatment.

THE PROBLEMS

Early EPA research on biological treatment of toxics was designed to assess the removals of toxics in efficiently operated and acclimated treatment systems. The studies evaluated the process performance using steady or consistent influent concentrations of mixtures of representative priority pollutants under acclimated operating conditions. Typical spiked concentrations of the individual toxic organic ranged from 50 µg/L to 200 µg/L in pilot-scale municipal wastewater treatment systems (3,4,5). In a limited industrial field study (6) without spiked toxics, the influent toxics concentrations were consistently present and usually ranged from less than 1 milligram to a few milligrams per liter of individual toxic.

The results revealed typically good removals, often more than 95 percent (Table I) for semivolatile priority organics (3) and often exceeding 98 percent (Table II) for the volatile priority organics (4). The removal of indigenous trace metals (Table III) in these studies, however, varied ranging from about 20 to 90 percent, depending upon the individual metals (5), with pass-through concentrations of possible environmental concern. Required "categorical" pretreatment of the metals industry's discharges should often lead to acceptable metals pass-through and content in the municipal plant's sludges from conventional biological treatment.

Table I. Distribution of Semivolatile Organics in the Spiked Treatment System

	Final Effluent Conc. (µg/L)	Overall % Rem.	% in Primary Sludge	% in Waste Act. Sludge	% in Final Eff.	Total Mass Recovered (%)
PESTICIDES/PCBs						
Arochlor 1254	< 2.9	98	51	60	2	113
Heptachlor	< 2.3	93	33	35	7	75
Lindane	25.8	45	12	8	55	75
Toxaphene	< 2.9	98	31	27	2	60
PHENOLS						
2,4-dimethylphenol	< 0.9	99	0	0.5	1.1	1.6
Phenol	< 13.5	95	4.4	0.8	5	10.2
Pentachlorophenol	< 6.3	19	26	5	81	112
PHTHALATES						
Bis(2-ethylhexyl)phthalate	11.3	79	63	39	21	123
Butylbenzylphthalate	< 1.3	96	119	7	4	130
Diethylphthalate	< 1.2	97	7	9	3	19
Dimethylphthalate	< 0.8	98	0.3	2	2	4.3
Di-n-butylphthalate	< 2.7	94	39	11	6	56
Di-n-octylphthalate	< 4.8	83	91	43	17	151
POLYNUCLEAR AROMATIC HYDROCARBONS						
Acenaphthene	< 1.2	97	41	4	3	48
Anthracene	< 0.9	97	67	5	3	75
Benz(a)anthracene	< 0.6	98	67	18	2	87
Chrysene	< 1.2	97	75	13	3	91
Fluoranthene	< 1.9	94	84	13	6	103
Fluorene	< 0.7	98	51	3	2	56
Napthhalene	< 0.7	99	22	0.5	1	23.5
Phenanthrene	< 1.1	97	59	1	3	63
Pyrene	< 2.0	94	107	7	6	120

Table II. Mean Concentrations Observed in the Experimental Treatment Sequence

	Inf. (µg/L)	Primary Eff. (µg/L)	Primary Sludge (µg/L)	RAS (µg/L)	Act. Sludge Eff. (µg/L)	Aer. Basin Off-gas (ng/L)	% Rem. by Primary Clarifier	% Rem. by Treatment Sequence
Methylene Chloride	118	89	<143	<21	<4.0	-	25	> 97
1,1-Dichloroethene	79	34	< 40	< 1	<0.2	425	57	> 99
Chloroform	137	143	<208	< 7	3.6	838	0	> 97
Carbon Tetrachloride	60	32	< 14	< 1	<0.2	322	47	> 99
1,2-Dichloropropane	309	295	<461	< 1	<6.0	1628	5	> 98
Trichloroethylene	107	68	389	< 1	<1.5	609	36	> 99
1,1,2-Trichloroethane	133	155	<219	31	28.0	663	0	80
Dibromochloromethane	58	49	< 10	< 2	<7.0	1291	16	> 88
Benzene	73	61	121	< 1	<0.2	225	16	> 99
1,1,1-Trichloroethane	132	96	<220	< 1	<0.3	1022	27	> 99
Bromodichloromethane	89	64	< 25	< 1	<0.2	1155	28	> 99
Chlorobenzene	197	163	953	< 5	<1.3	149	17	> 99
Tetrachloroethylene and Tetrachloroethane	252	263	2033	25	16.0	1227	0	94
Toluene	255	198	974	< 2	<0.6	672	22	> 99
Ethylbenzene	82	69	766	< 1	<0.2	243	16	> 99

In these past studies, selected individual organics were poorly removed. Lindane, as an example (3), substantially passed through the aerobic treatment process. Furthermore, for some priority organics, even with efficient removals, residual pass-through concentrations of the organics could pose possible environmental concern (3). Finally, an important observation was made during these studies. The steady or consistent influent concentrations at the moderate levels encountered or added produced no measurable inhibitory or interference effects on the biological systems.

Table III. Metals Removal in Control Treatment Systems

Metal	Inf. (mg/L)	Prim. Eff. (mg/L)	Removal by Primary Clarifier (%)	Activated Sludge Eff. (mg/L)	Removal by Activated Sludge (%)	Total Rem. (%)
Ag[a]	8.0	9.0	0.0	5.0	44.0	37.5
As[a]	20.6	16.0	22.3	16.7	0.0	18.9
Cd[a]	20.9	17.0	18.7	7.9	53.5	62.2
Cr	0.63	0.51	19.0	0.34	33.3	46.0
Cu	0.80	0.57	28.8	0.16	71.9	80.0
Fe	4.29	2.44	43.1	1.01	58.6	76.5
Hg[a,b]	2.0	2.0	-	2.0	-	-
Mn	0.65	0.55	15.4	0.40	27.3	38.5
Ni	0.45	0.27	40.0	0.18	33.3	60.0
Pb	0.88	0.58	34.1	0.11	81.0	87.5
Zn	1.24	1.28	0.0	0.46	64.1	62.9

[a]Micrograms/liter.
[b]The Hg concentration is near the detection limit for the metal and removals cannot properly be calculated.

The completed EPA research has also evaluated the removal of spiked representative toxics in alternative treatment systems (7), as possible technologies for use on marine wastewater discharges, where the conventional pollutants (BOD, solids, and nutrients) do not significantly impact the water quality. The alternative pilot-scale systems included primary sedimentation, primary sedimentation plus filtration, chemical treatment in primary sedimentation, high rate trickling filters, facultative lagoons, and aerobic lagoons. These systems were compared with a primary sedimentatation-activated sludge system. The overall results revealed that conventional primary sedimentation-activated sludge (mean cell retention time ~ 7 days) provided the best overall control of toxics. The lagoons provided lower but fair control of the toxics. The remaining systems permitted significantly increased pass-through of toxics.

The EPA supported treatability studies (8,9) to assess the removal mechanisms in biological treatment. The fate of the toxic organics during treatment revealed (Tables IV and V) that acclimated operation at influent concentrations ranging from about 700 µg/L to 20 mg/L, even with relatively recalcitrant pentachlorophenol, produced very efficient removals of the individual organics, usually greater than 99 percent for acclimated operation. These studies with acclimated operation, however, revealed that the competitive removal mechanisms in the treatment systems, although minimizing pass-through of the organics in the wastewater effluent, could partially transfer the toxics into the wastewater sludges or, for volatile organics, into the air. Unacclimated operation increased the importance of the abiotic removal mechanisms, as well as the pass-through of the specific toxics.

Agency surveys such as the 40-City Survey (10) of municipal treatment plants and the EPA studies of industrial treatment plants (11) revealed variable influent concentrations and removal efficiencies of the individual priority pollutants in biological treatment plants in the field. The greater performance variability and poorer treatment efficiencies in the field were more noticeable in the municipal than in the industrial plants.

Completed and ongoing toxicity reduction studies also reveal the pass-through of residual toxicity. A completed study (12) revealed (Table VI) the variable presence and substantive pass-through of mutagenic materials in municipal wastewaters. An ongoing study (13) shows substantive but

Table IV. Fate of Toxic Organics in Acclimated Activated Sludge Bioreactors Operated Under Steady-State Conditions

Compound	Percent of Influent			
	Effluent	Off-Gas	Biosorbed	Biodegraded
Benzene	< 1	16	0	84
Toluene	< 1	17	0	83
Ethylbenzene	< 1	22	0	78
O-Xylene	< 1	25	0	75
Chlorobenzene	< 1	20	0	80
1,2-Dichlorobenzene	6	59	0	35
1,2,4-Trichloro-benzene	10	90	< 1	0
Nitrobenzene	2	< 1	0	98
Lindane	96	0	4	0

highly variable influent ecosystem toxicity and variable pass-through of that toxicity. Finally, another ongoing study (14) reveals only moderate pass-through of toxicity but substantive impact of toxicity pass-through, markedly reducing the fish population in the receiving stream. The detailed progress in these ongoing studies are being described at this Conference.

The EPA research and the general literature clearly reveal the excellent potential of biological treatment for control of toxics in wastewater. It also reveals, however, toxics and toxicity pass-through, toxicity impacts on the environment, and occasionally, interference with the biological processes (15).

At this point, a brief overview of the biological treatment process is appropriate. Acclimation needs in metabolic

Table V. Phase II: Aerobic Testing Results

Compound*	SRT (days)	Compound in Feed (mg/L)	Compound Remaining in Eff. (µg/L)	Affected Other COD Removal?	Fate of Compound (%)			
					In Effluent	Sorbed on Solids	Volatilized	Biodegraded
PCP	3	20	214	No	1.07	0.31	0.03	98.6
	5	20	105	No	0.53	0.15	0.03	99.3
	7	20	68	No	0.34	0.10	0.03	99.5
	11	20	64	No	0.32	0.08	0.04	99.6
MCB	3	16.3	< 5	No	< 0.03	2×10^{-4}	< 7	> 93
	5	16.3	< 5	No	< 0.03	2×10^{-4}	< 11	> 89
	7	16.3	< 5	No	< 0.03	2×10^{-4}	< 16	> 84
	11	16.3	< 5	No	< 0.03	2×10^{-4}	< 21	> 79
DMP	3	20	< 5	No	< 0.03	$< 10^{-2}$	$< 10^{-2}$	> 99.9
	5	20	< 5	No	< 0.03	$< 10^{-2}$	$< 10^{-1}$	> 99.9
	7	20	< 5	No	< 0.03	$< 10^{-2}$	$< 10^{-1}$	> 99.9
	11	20	< 5	No	< 0.03	$< 10^{-2}$	$< 10^{-1}$	> 99.9
BEHP	3	2.64	138	No	5.2	55.4	$< 10^{-2}$	39.4
	5	2.64	75	No	2.8	15.5	$< 10^{-2}$	81.7
	7	2.64	66	No	2.5	13.3	$< 10^{-2}$	84.2
	11	2.64	68	No	2.6	18.7	$< 10^{-2}$	78.7

*PCP = Pentachlorophenol; MCB = Monochlorobenzene; DMP = Dimethylphthalate; BEHP = Bis-(2-ethylhexyl)phthalate.

(Continued)

Table V. PHASE II: Aerobic Testing Results (continued)

Compound*	SRT (days)	Compound in Feed (mg/L)	Compound Remaining in Eff. (µg/L)	Effected Other COD Removal?	Fate of Compound (%)			
					In Effluent	Sorbed on Solids	Volatilized	Biodegraded
TOL	3	26.1	< 5	No	< 0.02	$< 10^{-2}$	< 21	> 79
	5	26.1	< 5	No	< 0.02	$< 10^{-2}$	< 32	> 68
	7	26.1	< 5	No	< 0.02	$< 10^{-2}$	< 48	> 52
	11	26.1	< 5	No	< 0.02	$< 10^{-2}$	< 60	> 40
NAPTH	3	4.24	< 5	No	< 0.12	0.23	< 29	> 71
	5	4.24	< 5	No	< 0.12	0.19	< 32	> 68
	7	4.24	< 5	No	< 0.12	0.19	< 68	> 32
	11	4.24	< 5	No	< 0.12	0.20	< 84	> 16
PCMC	3	20	7.9	No	0.08	3.04	$< 10^{-2}$	96.9
	5	20	4.8	No	0.05	0.95	$< 10^{-2}$	99.0
	7	20	4.0	No	0.04	0.83	$< 10^{-2}$	99.1
	11	20	5.0	No	0.05	1.26	$< 10^{-2}$	98.7
DNOC	3	20	666	No	6.7	0.11	0.47	92.7
	5	20	760	No	7.6	0.17	0.50	91.7
	7	20	301	No	3.0	0.02	0.32	96.7
	11	20	85	No	0.85	$< 10^{-2}$	0.14	99.0

*TOL = Toluene; NAPTH = Napthalene; PCMC = Parachlorometacresol; DNOC = Dinitroorthocresol.

Table VI. Mutagenicity in the Ames Test of Municipal Wastewater Samples at Various Treatment Stages

Treatment Plant	Wastewater Type	Sample Date	Treatment Stage	Total Liters Extracted	Conc.[a] (mg/L)	Net Revertants/mg -S9	Net Revertants/mg +S9	Net[b] Revertants/Liter
Mill Creek T&E Fac.	Industrial/ Domestic	9/2/81	Raw Wastewtr	2	48.8	173	381	18,600
			Primary Eff.	2	41.8	1,057	524	21,900
			Secondary Eff.	6	4.9	169	1,380	6,700
			Secondary Eff. + Cl_2	6	4.6	196	1,770	8,100
		9/9/81	Raw Wastewtr	2	66.5	N.D.[c]	180	12,100
			Primary Eff.	2	46.0	77	390	18,000
			Secondary Eff.	6	4.6	5,645	4,070	18,900
			Secondary Eff. + Cl_2	6	4.0	6,370	4,320	17,300
Mill Creek Plant	Industrial/ Domestic	8/31/82	Raw Wastewtr	8[d]	91.0	N.D.[c]	89	8,100
			Secondary Eff.	50[d]	7.7	417	353	2,700
		6/20/83	Primary Eff.	23	70.4	N.D.[c]	129	9,100
			Secondary Eff.	86	8.7	693	761	6,600
Muddy Creek Plant	Domestic	1/11/83	Raw Wastewtr	24[d]	36.8	N.D.[c]	N.D.[c]	-
			Secondary Eff.	92[d]	2.2	161	175	385

[a]Refers to the concentration of extractable organics based on the residue weights of the extracts.
[b]Based on the mutagenicity values from the assays with S9 activation.
[c]N.D. = not detectable (i.e., response at any sample dose level was less than 2-fold above control.)
[d]Extraction at pH 11.0 was omitted.

processes of microorganisms may place limitations on the treatability of individual compounds in conventionally operated biological treatment. While diverse microbial populations occurring in the treatment of complex wastewaters are adaptive and thus can successfully degrade a wide range of organic compounds, the multiple organic nutrients in complex wastewaters, have variable thermodynamic-free energies available to support the metabolic activity of microorganisms. Indeed, individual organics (16) exhibit different effective energy for metabolic activity in different microorganisms and different degradation rates.

Recalcitrant organics--those with low available free energy, in the presence of sources of organics with more available free energy--may not be efficiently removed in the treatment available in the plant. The available data suggests that only a very small fraction of the toxics will be strongly recalcitrant to biodegradation producing substantive pass-through. More importantly, the acclimation of a much higher fraction of the toxic organics by the diverse microbial population in the process can be ineffective because of intermittent and highly variable amounts of the specific organic entering the industrial or municipal treatment system.

The abiotic competing removal mechanisms of volatilization and partitioning to the solids, although reducing water pollution, also cause other media pollution concerns. Transfer of volatile organics into the air from sewers, head works and the aerobic biological processes, even when substantive biodegradation occurs, cannot be fully prevented in conventionally operated wastewater treatment. Toxic compounds, especially the metals, partition to the sludges thus complicating the solids disposal processes on the land. Clearly, innovative operational approaches will be needed to minimize the limitations of conventionally operated wastewater treatment and to ensure, for control of toxics, more effective use of the substantial resources already invested in state-of-the-art wastewater treatment technology.

EPA RESEARCH APPROACH

With both problems and the treatment potential of biological treatment, an EPA approach is evolving to enhance the treatment potential and to minimize the problems. The toxics

control program for wastewater treatment in the Agency's Water Engineering Research Laboratory in Cincinnati is following a three path approach in research. These paths are:

- treatability research on representative specific toxics,
- toxicity detection and reduction in treatment and pretreatment, and
- innovative concepts to enhance control of toxics in biological treatment.

Treatability Research

The treatability research aims at evaluating the equilibrium and kinetics relations of the principal removal mechanism in conventional primary-secondary (biological) treatment. The important mechanisms are:

- partitioning (sorption) on solids and biomass,
- volatilization (air stripping and surface desorption), and
- biodegradation (aerobic and anaerobic)

The goals of the research include developing appropriate bench-scale treatability protocols for experimentally determining the fate of specific toxics in and their impact on the conventional primary-secondary treatment system; determining kinetic and equilibrium data on representative toxics for the principal treatment mechanism; and, using the experimental data, developing predictive models for estimating the fate of toxics in conventional treatment from the chemical properties and structural activity relations of the individual toxics.

Substantive progress using first generation protocols has already been achieved. A paper (17) presented at this Conference describes an excellent correlation between the partitioning coefficient of organics from the water to the solids and biomass in wastewaters and the octanol/water partition coefficient of the individual toxics. The work also describes the kinetic rates for the partitioning of the toxics.

In volatilization, an early predictive model (18) developed for the EPA was only successful in predicting stripping from "clean water." The poor predictive performance, when the model was applied to biological treatment systems, was ascribed to solids and to biological activity

in the biological process. Current volatilization studies (19) at the Water Engineering Research Laboratory have revealed that after partitioning equilibrium has been established, the stripping rate proceeds independently of the solids in the water (Figure 1). The solids do not affect the stripping rate as long as biodegradation is inhibited or does not occur. Further work is needed to establish the effects of surface active materials on the stripping process.

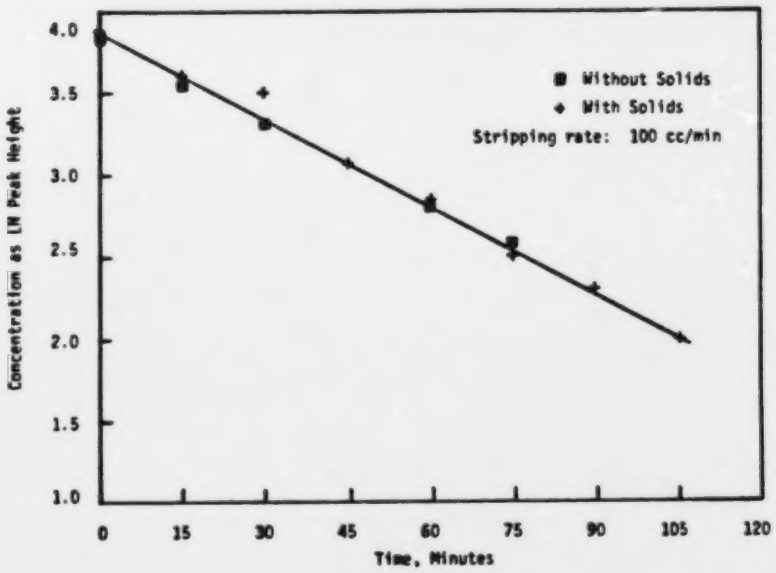

Figure 1. Impact of solids on stripping of chlorobenzene.

Initial progress on the biodegradation mechanism has also been achieved using an advanced electrolytic respirometric approach (20) to indicate relative acclimation requirements, intrinsic growth rate kinetics and kinetic inhibition rates for a few compounds. The technique (Figure 2) reduces the manpower required to develop the biodegradation data and, within two years, should provide a modest but sophisticated data base on representative toxics.

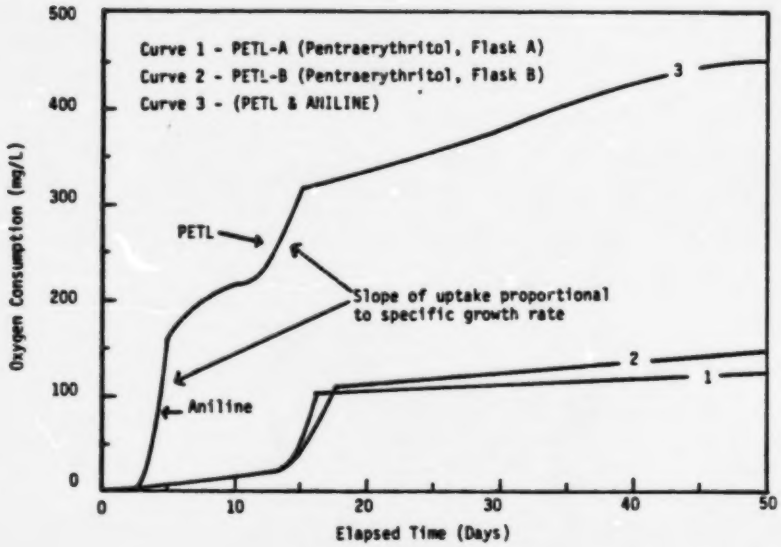

Figure 2. Biochemical oxygen uptake curve.

Successful but limited predictive models have already been developed (8) where appropriate experimental kinetic and equilibrium data have been established for the principal removal mechanisms. The current progress on the abiotic mechanisms and the relatively inexpensive development of the modest but sophisticated biodegradation data base suggest probable future success in developing tools for predicting the fate of toxics in conventional wastewater treatment by using the chemical properties and structural activity relations of the specific toxic compounds.

This research path also includes specific treatability studies on selected specific toxics for industrial treatment and pretreatment. When biological processes or conditions detrimental to biological treatment prevent successful control through biological methods, appropriate physical-chemical treatment options are being evaluated for these specific problem toxics but are beyond the scope of today's presentation.

Toxicity Detection and Reduction

The Agency goals for research on toxicity detection and reduction in treatment and pretreatment are to:

- develop procedures for industrial and municipal wastewater treatment plants to isolate and identify the causes of effluent toxicity, and
- develop procedures to remove this toxicity either at the source or by enhanced treatment at the central plant.

The research approach features the conducting of case history studies called toxicity reduction evaluations (TREs) on plants known to pass-through toxics or toxicity. In these research TREs, the Agency is testing candidate alternative procedures for monitoring the treatment plants, for tracing the toxics or toxicity to their sources, and for identifying the specific toxics. Near real-time and inexpensive in-plant monitoring tools, which are alternatives to the classic bioassays for toxicity and conventional analytical methods for specific toxics, are also being evaluated. These monitoring alternatives include MICROTOX toxicity (21), respirometry (oxygen uptake methods) and adenosine triphosphate measurements.

The elements of a TRE at a treatment plant, after a problem of toxicity or toxics pass-through has been established, are shown in the Table VII. The results of the initial TRE studies (13,14,22), conducted at industrial and municipal wastewater treatment plants with good treatment of conventional pollutants but with toxicity pass-through problems, will be used to prepare Toxicity Reduction Evaluation Protocols for use by the wastewater treatment field.

Innovative Approaches to Enhance Toxics Control-- The Opportunities

The above research paths are developing tools to increase regulatory effectiveness for toxics, especially through identifying and characterizing toxics problems in conventional wastewater treatment plants. Knowledge from treatability studies including the pretreatment studies

should also increase the effectiveness of toxics control by conventionally operated biological wastewater treatment systems. The problems of intermittent toxics pass-through and intermedia pollutant transfer, especially of volatiles to air, however, indicate a need for innovative approaches in biological treatment of wastewaters.

Table VII. Elements of a Toxicity Reduction Evaluation

• Evaluating in the Treatment Plant the Causes of Toxicity Pass-Through.
A. Plant Operations Deficiency.
B. Presences of Refractory Toxicity.
• Tracing Toxicity to Sources.
A. Bioassay Monitoring in Source Treatability Studies.
B. Alternative Monitoring Techniques.
• Identifying Toxicity Components.
A. Specific Chemical Identification.
B. Bioaccumulative Potential of Specific Toxics.
• Evaluating of Control Alternatives.
A. Industrial Process Modifications.
B. Pretreatment Alternatives
C. Central Treatment Plant Control of Toxicity

Studies in microbiology suggest that operational approaches can be used to increase degradation of recalcitrant compounds. A kinetics study in multiple carbon-source-limited growth (23) revealed that, under carbon-limited growth conditions, biogenic multiple carbon sources are used simultaneously and not sequentially by steady-state cultures of a marine bacteria. Additionally, the presence of multiple substrates produced substantially lower residual steady-state concentrations of the individual biodegradable substrate. Recently completed studies further reveal that the presence of multiple biogenic compounds under carbon-limited growth conditions also increases the growth rate and reduces the steady-state concentration of the recalcitrant xenobiotic organics in acclimated bacterial cultures; in one case (24), pentachlorophenol; in a second case (25), 2-chlorophenol.

These studies indicate that operational and microbiological mechanisms of metabolism to increase treatment efficiency of toxic organics are favored by the availability and/or control of:

- sufficient nitrogen, phosphorus, and trace nutrients,
- Appropriate dilution to prevent toxic inhibition,
- Co-metabolites, and
- Diverse microbial populations for improved adaptability.

Such conditions in wastewaters are usually best found in central municipal and industrial wastewaters. THE CHALLENGE THEN IS TO USE THE CENTRAL FACILITIES IN INNOVATIVE OPERATIONAL APPROACHES TO BETTER CONTROL THE TOXIC COMPOUNDS.

The Water Engineering Research Laboratory in Cincinnati, Ohio, has identified a series of innovative operational approaches to meet the challenge. Some of these approaches are being evaluated in ongoing research and TRE work. Others will undergo proof of concept testing as resources become available. The operational approaches are:

- controlled discharges of toxics into treatment,
- additives for improved toxic removal (clays, binding proteins, carbon, enzymes, etc.),
- anaerobic-aerobic treatment combinations,
- alternative operation of selected central plants as detoxification facilities, and
- bioengineered organisms.

The ongoing TRE studies are evaluating the effects of controlled discharges of toxics into the central treatment system. Simple storage and controlled releases should reduce the slugs of toxics currently reaching central treatment systems and thus minimize toxic pass-through as well as reduce chances for interference effects. The Laboratory is also supporting and has supported work on the use of additives in the central treatment system. Completed work includes assessment of powdered activated carbon as an additive in the biological process (8). Ongoing work involves developing and testing protocols with the National Sanitation Foundation (26) for the evaluation of bioaugmentation products. The testing protocols are being used to evaluate treatability effectiveness of existing bioaugmentation

products, including microorganisms and their enzyme products, but can be applied to advanced products from bioengineering research.

The Water Engineering Research Laboratory also has a modest bioengineering research effort, cooperatively conducted with the Agency's Hazardous Waste Engineering Research Laboratory in Cincinnati, Ohio. In the toxics area, two projects are already showing promise. Recently, investigators (27) at Battelle-Columbus Laboratories isolated a pure culture of an anaerobe (called DCB-1) able to dehalogenate 3-chlorobenzoate (3-CBA). The gene coding for the anaerobic dehalogenating ability was found on the chromosome rather than on a plasmid. They next created a gene library of DCB-1 and cloned the entire chromosome into Escherichia (E.) coli. From this they were able to isolate a number of E. coli clones that contained pieces of the DCB-1 chromosome.

They are now testing those clones for expression of the 3-CBA activity. If E. coli is able to express the activity, it will be a major step forward, since it opens up a whole host of possibilities. For example, E. coli will be able to dehalogenate 3-CBA under facultative rather than strictly anaerobic conditions. It will be able to mobilize the activity into other species. Also, since it is hardier and able to grow much faster than anaerobes, it might be possible to obtain huge quantities of the enzyme cheaply and easily for possible use in the field instead of live organisms. The advantage of this lies in the fact that at present live cells of DCB-1 are not able to dehalogenate 3-CBA under sulfate-reducing conditions. The immobilized enzyme would.

Another factor is that the present anaerobe DCB-1 can only dehalogenate 3-CBA; it cannot grow on the product of the dehalogenation, benzoate. If the gene for 3-CBA dehalogenation were given to an organism able to grow on benzoate, then that organism could convert 3-CBA all the way to CO_2 and water.

In a second project (28) investigating the removal of the heavy metal cadmium from wastewater, researchers at the University of Washington, Seattle, have recently found that E. coli makes a cadmium binding peptide that is secreted outside the cell. In its native state, it is a high molecular weight aggregate of the peptide and cadmium bound tightly together. When the aggregate is reduced, the actual peptide is a low molecular weight molecule able to bind very tightly to cadmium. The investigators are trying to purify the peptide and deduce its chemical structure. Once that is

done, it will then be immobilized onto a surface for the purpose of defining the binding kinetics to cadmium in aqueous solution.

From this work, the investigators have hypothesized a mechanism for the biological removal of cadmium in the environment. They suggest that the organism secretes the binding protein outside the cell, where it complexes with the toxic cadmium and prevents entry of the metal into the cell. The work can lead to innovative separation techniques for the control of cadmium in wastewaters.

Anaerobic-aerobic treatment combinations will be evaluated for improved toxics control in various alternative approaches. The TRE at the Patapsco Plant in Baltimore, Maryland, will assess the effect of sequential facultative anaerobic-aerobic operation on toxicity pass-through when the plant is converted to biological phosphorus removal. An anaerobic operating phase in a single sludge system will be used at Baltimore for biological phosphorus uptake. Indeed, bioengineered facultative dehalogenation developed in facultative organisms from the bioengineering research area may have a future role in the control of chlorinated organics in such operations. A second approach involves the use of separate stage anaerobic treatment, either as a pretreatment step at the toxics source or as a separate stage anaerobic process at the central treatment plant. The anaerobic treatment possibilities lead to the concept of using separate innovative operations at the central plant as a detoxification facility.

The substantial public and private investment in central conventional wastewater treatment systems can potentially be used to improve toxics control, not only in wastewater, but for toxics wastes in general. The use of selected central treatment plants as detoxification facilities requires unconventional operation of the wastewater collection and treatment systems. The potential for use as a detoxification center can be simply illustrated by describing several possible operational examples.

In the first example, the central industrial or municipal treatment plant may have capacity to successfully treat additional amounts of toxic wastes. These wastes are simply fed at the central plant into the wastewater at rates the plant can handle.

The next example involves the use of the central plant for treating the high COD leachates from landfills currently polluting groundwater. The leachates, usually from municipal

landfills may or may not contain toxic components. Completed work (29) has evaluated the conventional treatment of these leachates by the central plant using sewers as the transport vehicle. Although technically feasible, such an approach produces substantive energy demands for aeration at the central plant and requires efficient anaerobic digestion of the difficult-to-digest aerobic biomass produced from the leachate.

An unconventional operational approach is to transport the high strength waste or leachate by truck directly to the central plant's digesters. Leachates, with substantive fatty acid contents from the landfill's incomplete anaerobic activity, are ideally suited for direct anaerobic digestion, using the diverse biomass and excess nutrients of the central treatment plant. The excess gas produced as recoverable energy may even exceed the energy requirements for the leachate transport. Such an approach also can be applied to anaerobically degradable toxics wastes currently handled in hazardous waste landfills.

Another example involves improved control of volatile toxic organics. The current operational approaches in central industrial or municipal wastewater treatment plants do not fully prevent volatilization transfer of at least a portion of the volatile organics into the air media. Even good biodegradation of the moderately volatile organics (Henry's Law Constant ~10^{-3} m^3 atm/mole) such as benzene and toluene will, under acclimated conditions, only minimize the volatilization transfer (8). Compounds with Henry's Law Constant greater than those of the moderately volatile organics will exhibit increased volatilization transfer as their Henry's Law Constants increase, even in acclimated biological operation. Current techniques for controlling this problem include the use of steam distillation at the discharge source of these solvents to prevent their release into the atmosphere.

An unconventional operational alternative, however, could involve truck transport of wastewaters, at least those with reasonably high concentrations of volatiles, to the central plant for direct treatment in the plant's anaerobic digestion processes, or in specially established aerobic bioreactors, where control of the gas phase can be cost-effectively managed. Such reactors could include aerobic digesters using pure oxygen with oxygen recycle.

The use of special bioreactors to separately control recalcitrant toxic waste independently transported to the

industrial or municipal wastewater treatment plant permits establishing a wide range of biological detoxification capabilities at these plants. Carbon-limited operation, with suitable co-metabolites, diverse biomass, nutrients, and appropriate dilution can be tailored to cost-effectively maximize the biodegradation of various recalcitrant toxic wastes. Aerobic-anaerobic treatment configurations can be readily established with back-up sources of organisms, co-metabolites and nutrients available from the central plant. To protect the bioreactors, rapid aerobic and anaerobic inhibition tests would be incorporated in the operational approach to determine appropriate feed rates to the reactors from toxic waste storage tanks. Indeed, a candidate aerobic inhibition test (30,31) using a batch-fed reactor is being described at this Conference.

As bioengineered organisms are developed, these organisms can be incorporated and controlled in the special reactors. The discharge from the special reactors could then be additionally treated through the treatment plant's main process system as back-up protection. Waste sources identified through TREs as being poorly treatable by conventional sewer transport and biological treatment would then have several alternative control options available including industrial inplant modifications, pretreatment at the discharge point and separate transport to a biological detoxification site at a central wastewater treatment plant.

INTEGRATED SYSTEM ENGINEERING

As a futuristic view, we envision an integrated systems engineering approach evolving--one that will take full advantage of technical, economic, and administrative capabilities of central water and wastewater treatment to control both toxics and traditional pollutants. The approach would include elements to prevent toxics transfer to the air, land, or groundwater. From the perspective of this Conference, the integrated management approach will focus on regulatory control of surface water quality using water quality-based permits.

The individual technology components in the integrated system (Figure 3) and in-stream water quality models for toxics are basically available. The linkage of the water

supply quality and wastewater treatment effluent characteristics through the receiving water should soon be documented by Agency supported research to characterize surface water quality (32) and to develop surface water quality models (33) for assessing the impacts of effluent discharges and pollutant spills on the water quality of the lower Mississippi River.

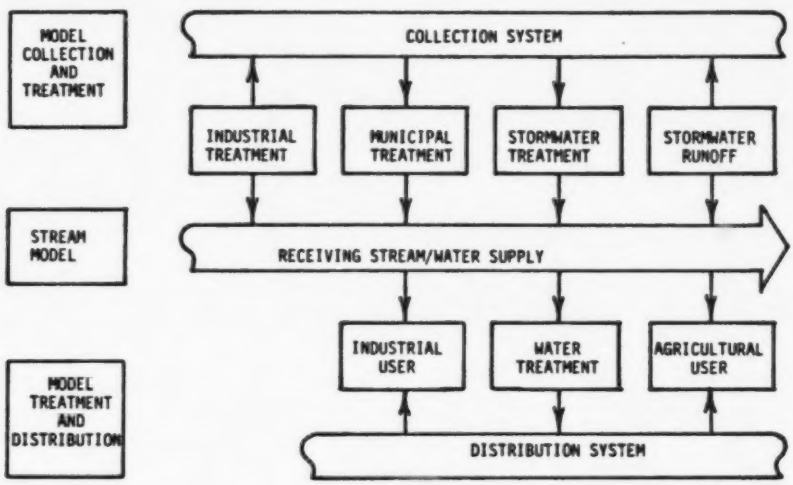

Figure 3. Components of the systems engineering concept.

The primary emphasis in the Mississippi study is on the movement of organics within the river and the effect discharges, under varying hydrological conditions, can have on concentrations of residual toxics at the raw waster supply intakes. As the Agency develops increasingly stringent maximum contaminant limits (MCL) for toxics in water supplies, the water utilities will be tempted to recover their increasing costs of treatment for drinking water from the upstream dischargers of the toxics. The linkage between wastewater effluent quality and water supply quality will strengthen the integrated systems engineering concept.

CONCLUSIONS

The toxicity impact on receiving water ecosystems, bioaccumulative uptake of toxics into the food chain, and effects of toxic discharges in wastewater effluents on the water quality of drinking water are strong factors driving the demand for improved technology for control of toxics. Ongoing EPA research should soon provide the scientific tools to support regulatory action by defining the environmental fate and effects and the health risk of toxics, by identifying the presence of toxics and toxicity in water and wastewater, and by tracing the toxics or toxicity to their sources. Effective toxics risk management through risk reduction, however, will require successful improvement of control technology.

The EPA is thus addressing approaches to improve control technology for managing toxics in wastewater. The costs for satisfactory control of the toxics will drive the EPA and the researchers in control technology to search for increasingly efficient and innovative technology. Systems engineering techniques will evolve to provide the tools for selection of technically effective and least costly combinations of control technology in industrial and municipal wastewater treatment and pretreatment and water treatment to meet the water quality and food chain requirements.

We at the EPA and you researchers in the field must meet the challenge for that technology innovation. This Conference addresses the critical core of the control technology--innovation in biological wastewater treatment. Best wishes in your endeavors this week.

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